TRMM Reentry Review

Trajectory Design

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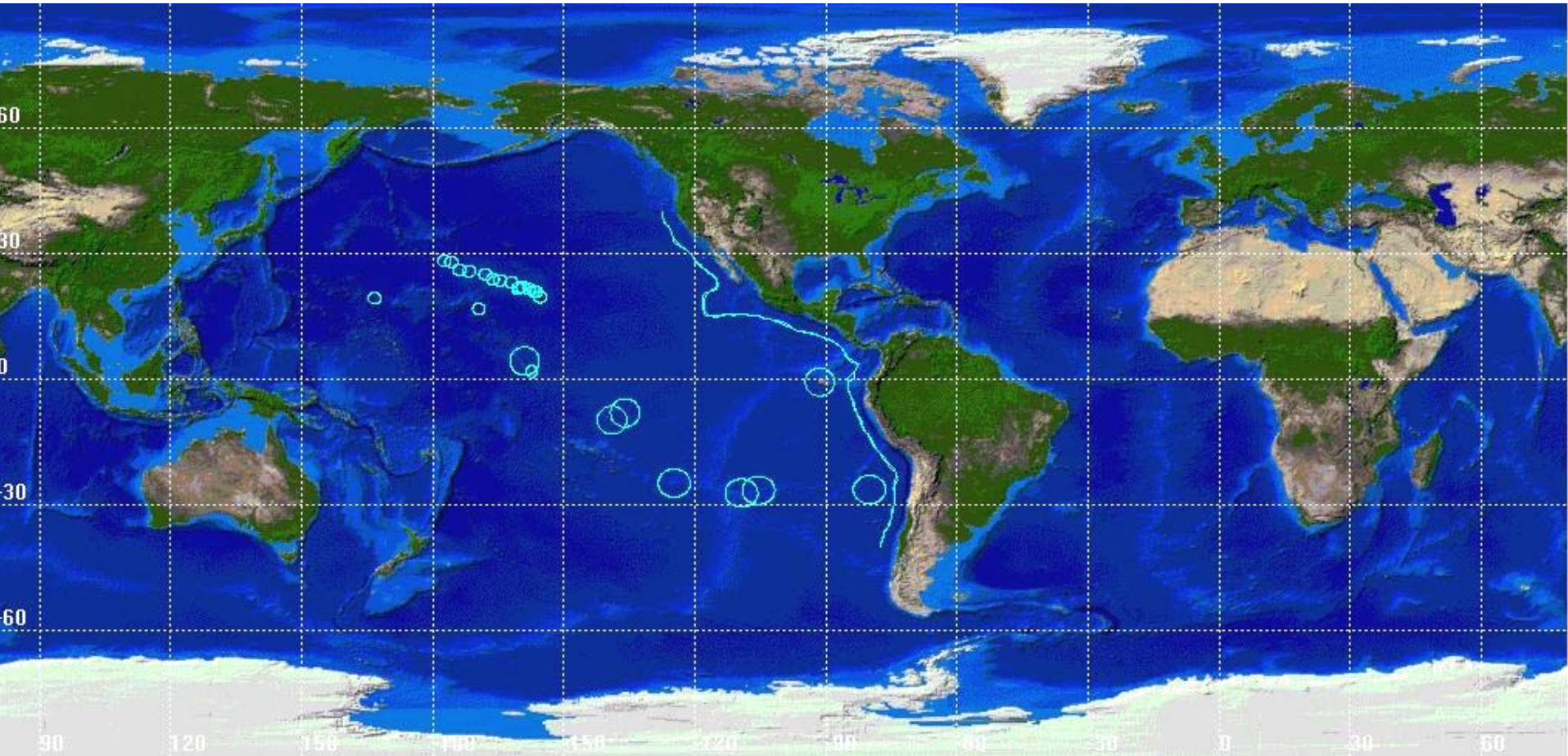
Agenda

- Targeting Considerations
- Design Drivers and Constraints
- Nominal Maneuver Scenario / Propellant Budget
- Optional Drivers and Constraints
- Variation Modeling
- Impact Footprint
- Contingencies

Targeting Considerations

- Target Area - Pacific Ocean
- NSS 1740 states that debris shall impact no closer than:
  - 200 nautical miles (370.4 km) from international territories
  - 25 nautical miles (46.3 km) from United States territories

TRMM Nominal Impact Target Area

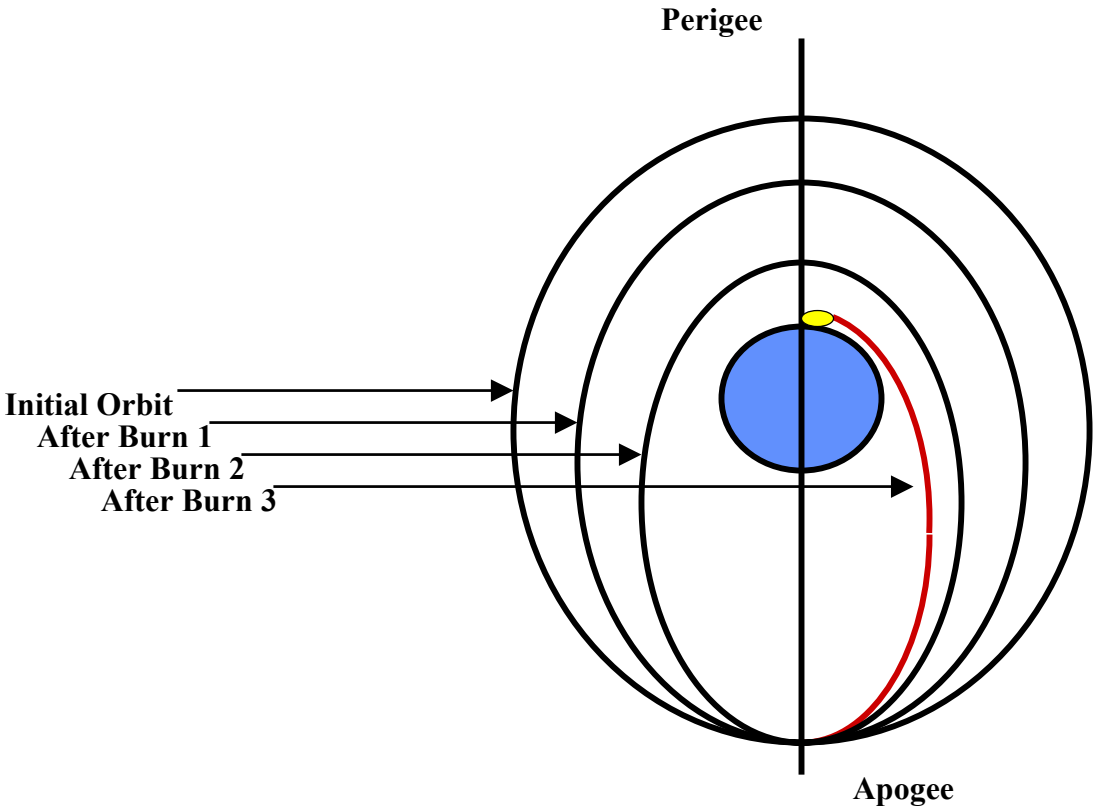


Design Drivers and Constraints

- Impact footprint must conform to NSS 1740 guidelines
- Total propellant for re-entry operations: 134 kg @ 978.4 kPa
  - Current Estimate: Mar 04 (+2 Sigma Flux), Oct 05 (Nominal Flux)
- Maneuver sequence initiated when orbit altitude reaches 320 km
  - Decay from 402 km, 12.5 m^2: 1.6 yr (+2 Sigma Flux), 3.0 yr (Nominal Flux)
  - Decay from 402 km, 17.0 m^2: 1.0 yr (+2 Sigma Flux), 2.2 yr (Nominal Flux)
- Maneuver length no greater than 45 minutes
- Minimum perigee height prior to final maneuver $\geq$ 150 km
- Minimum perigee height after final maneuver $\leq$ 50 km
- Approximately 1 day between first and second maneuvers to allow for orbit determination and post-maneuver reconstruction and calibration to verify propulsion system performance
- Final two maneuvers on back-to-back orbits
- Two back-to-back opportunities for final maneuver

Nominal Maneuver Scenario

Incrementally Drop Perigee Until Spacecraft Hits Dense Atmosphere and Re-enters on Target



Nominal Maneuver Scenario / Propellant Budget

- Sequence of three maneuvers
  - **Maneuver 1 centered on argument of latitude of ≈ 320° which defines initial orientation of line of apsides with respect to the target zone**
    - » **Can be performed during any orbit**
    - » **Perigee over target zone for approximately 10 days**
      - **Apsidal rotation rate of ≈ 10°/day**
      - **Perigee migrates back over target area in ≈ 35 days**
      - **Post-maneuver orbit lifetime ≈ 32 days**
  - **Maneuvers 2 & 3 centered on orbit apogee**
    - » **Longitude of ascending node target for Maneuver 2 of ≈ 160° to place re-entry track over the target zone**
    - » **Two opportunities per day**
      - **Can accommodate a one orbit delay for either maneuver (but not both)**
    - » **Post-maneuver 2 orbit lifetime ≈ 4 days**

Nominal Maneuver Scenario / Propellant Budget

- Maneuver Summary – October 2005
  - **Maneuver 1 - 312 x 220 km**
    - » **Centered on argument of latitude of 320°**
    - » **Duration: 28.22 minutes**
    - » **Delta V: 29.20 m/s**
    - » **Propellant Required: 34.95 kg**
  - **Maneuver 2 – 308 x 155 km**
    - » **Centered on apogee approximately 24 hours after Maneuver 1**
    - » **Duration: 19.31 minutes**
    - » **Delta V: 21.68 m/s**
    - » **Propellant Required: 23.35 kg**

Nominal Maneuver Scenario / Propellant Budget

- Maneuver Summary (cont'd)
  - **Maneuver 3 - 292 x 50 km**
    - » **Centered on apogee one orbit after Maneuver 2**
    - » **Duration: 35.43 minutes**
    - » **Delta V: 39.20 m/s**
    - » **Propellant Required: 41.76 kg**
  - **Summary**
    - » **Duration: 82.96 minutes**
    - » **Delta V: 90.08 m/s**
    - » **Fuel Required: 100.06 kg (Nominal Delta V only)**
    - » **Propellant Remaining: 33.94 kg**

Optional Drivers and Constraints

- Re-entry from 402 km
  - **Requires additional maneuver to reduce perigee to 320 km**
  - **Requires additional 25 kg of propellant for a total of 159 kg**
- Lighting constraints on maneuvers
  - **8 – 10 day window every 34-36 days if constrained by lighting conditions**
- Extended final maneuver
  - **Stop burn at approximately 140 km**
  - **Duration: 43.25 minutes**
  - **Additional propellant required: 9 kg**
  - **Final perigee altitude: 31.5 km**

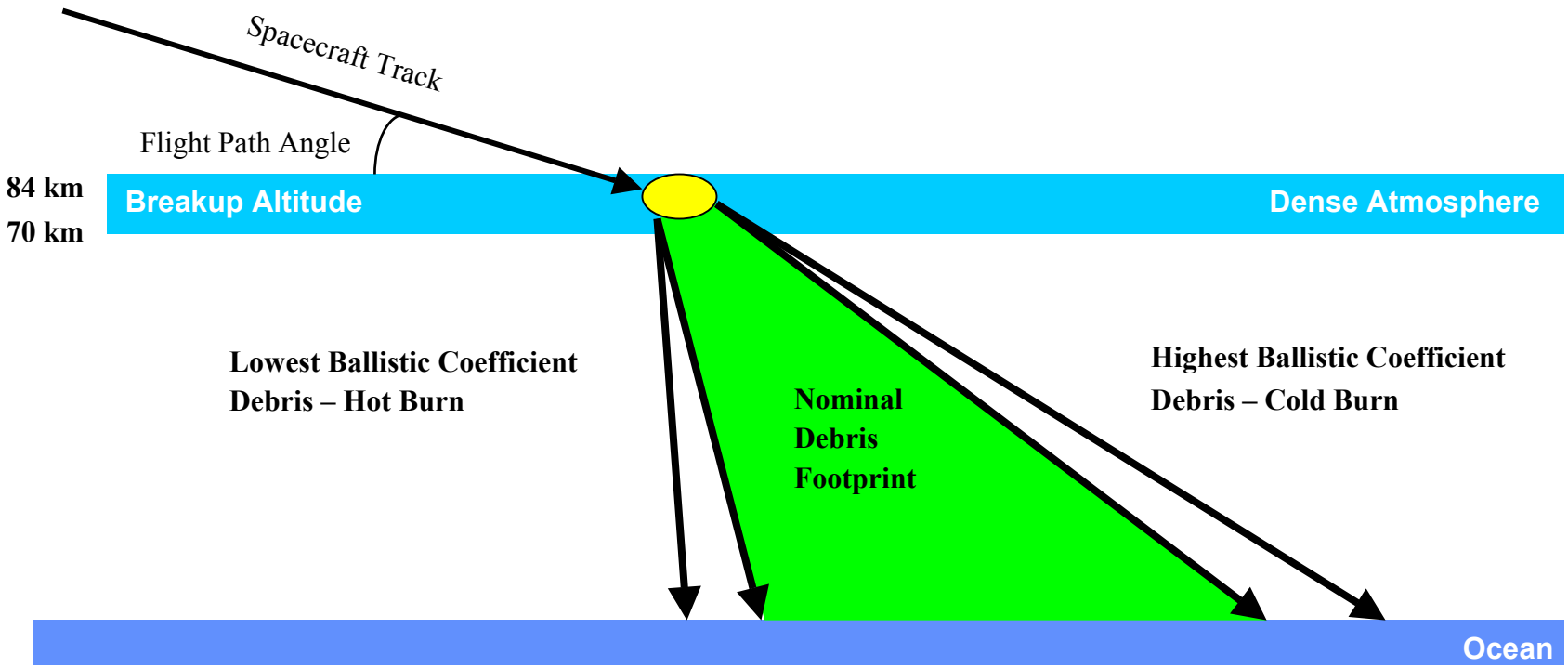
Variation Modeling

- Ballistic Coefficient
  - **Nominal (intact spacecraft): 119.49 kg/m^2**
  - **Light: 2.5 kg/m^2**
  - **Heavy: 177.5 kg/m^2**
  - **Conservative - Assumes all debris survives to impact**
  - **Spacecraft is assumed to break up at an altitude of 84 km. A separate propagation is performed based on each ballistic coefficient from this point to impact**
- Hot/Cold Burns
  - **Burn 1: Nominal**
    - » **Variations accounted for by re-targeting subsequent burns**
  - **Burns 2 & 3: $\pm$ 10%**

Impact Footprint

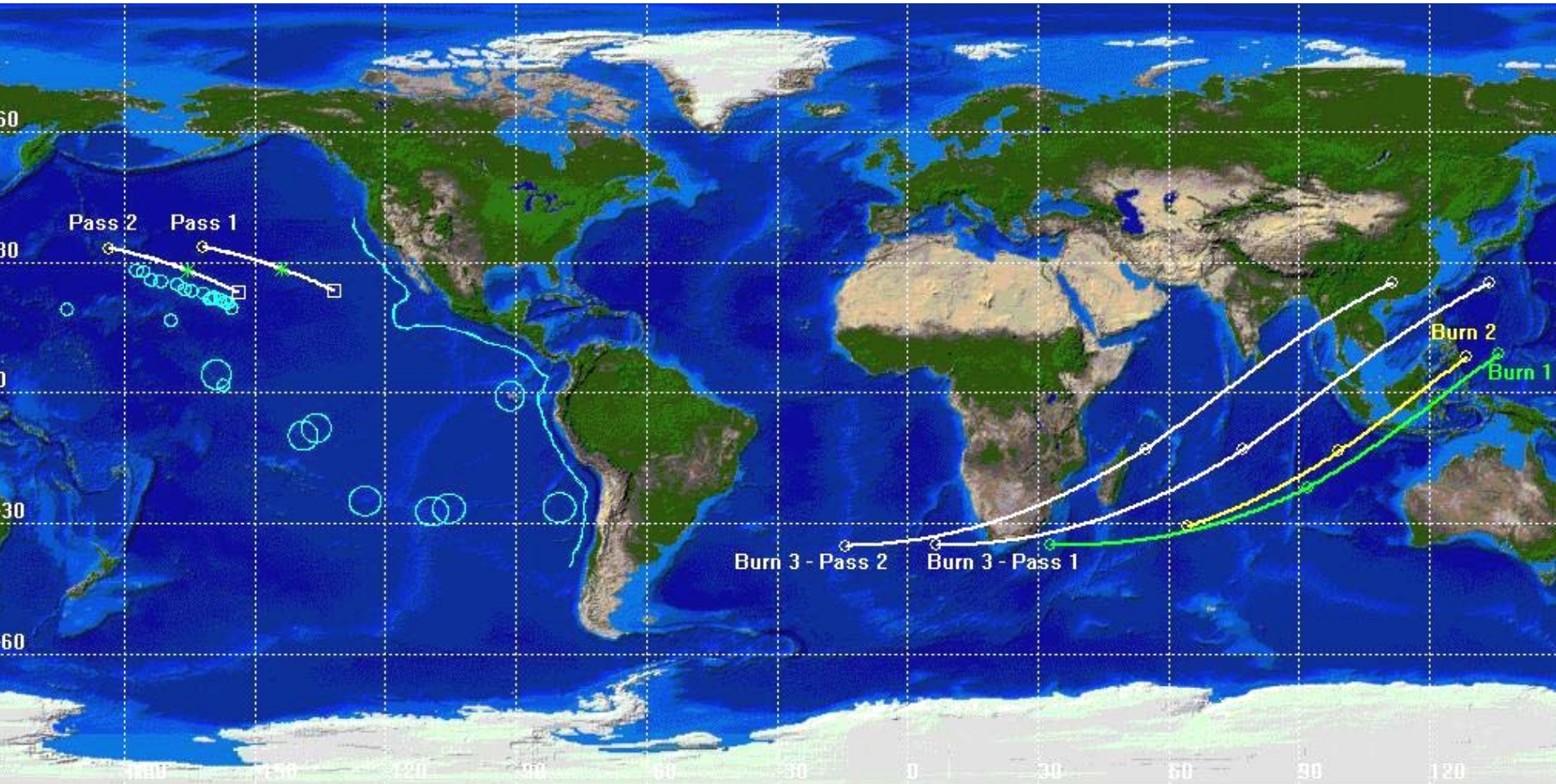
Spacecraft Re-entry / Impact Footprint

Spacecraft Hits Atmosphere at a Steep Angle, Dramatically Slows Down, Breaks Up, and Falls into Ocean



TRMM Impact Footprint

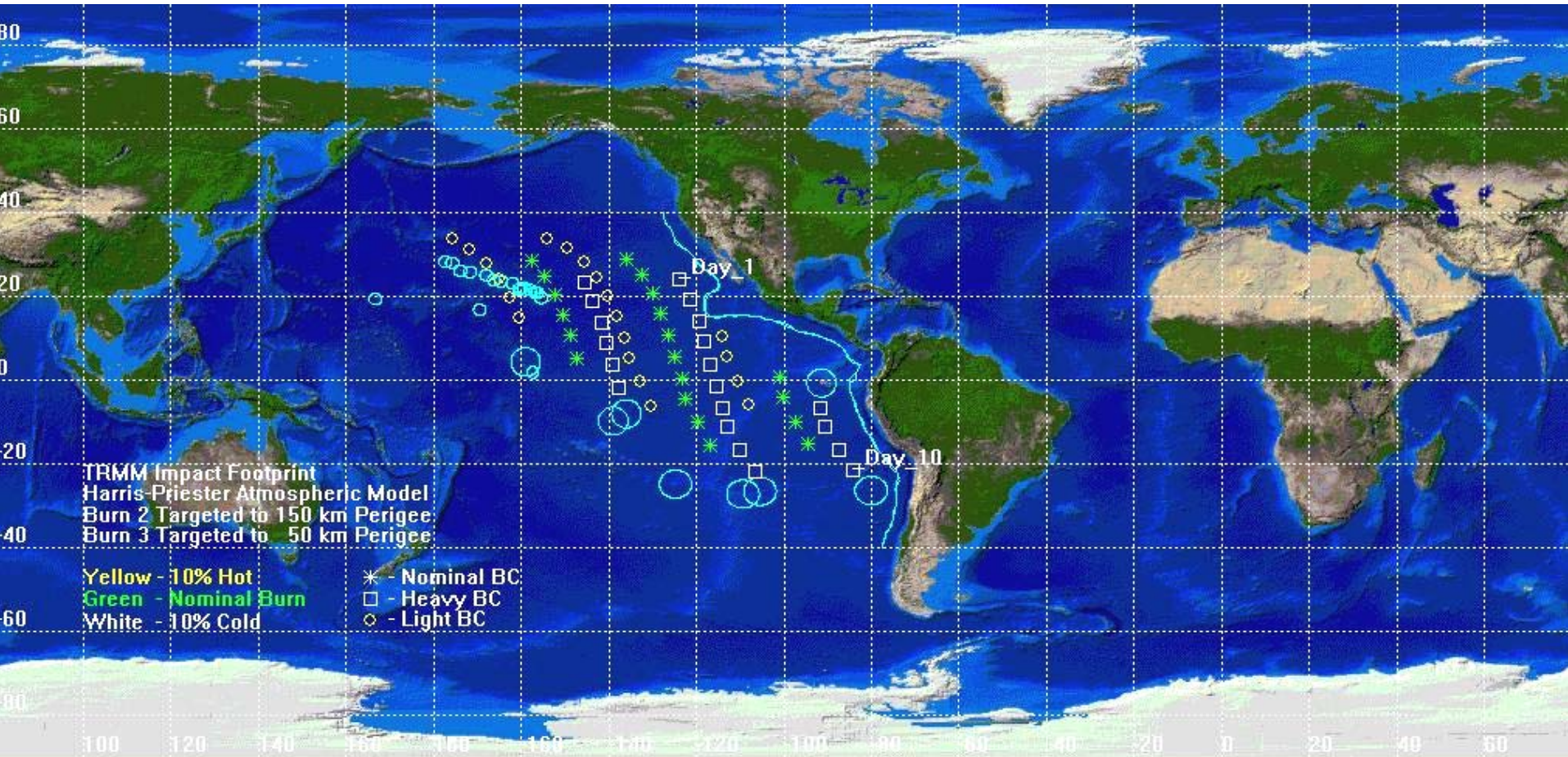
Nominal Case – 3136 km



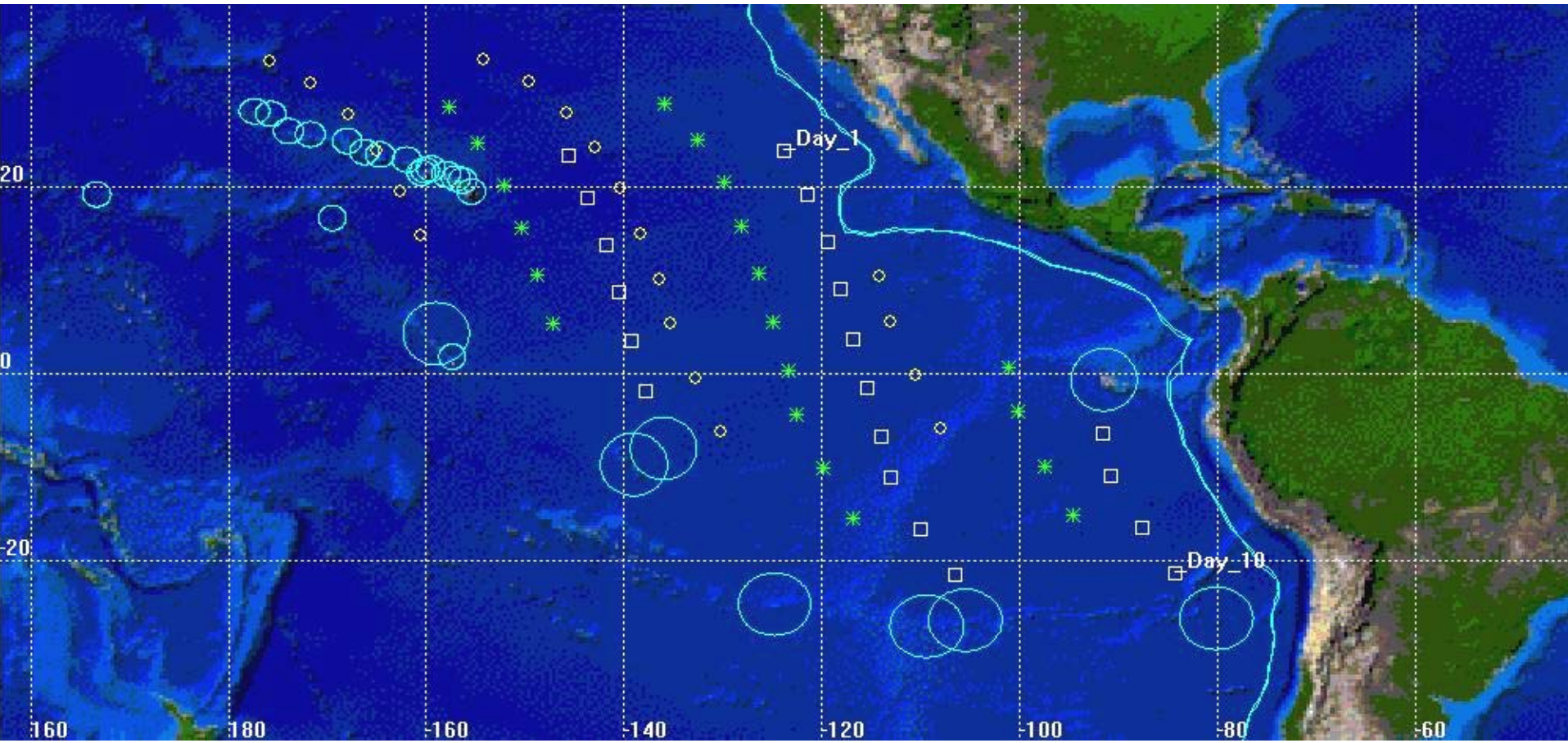
Contingencies

TRMM Impact Footprint
Effect of Burn 2 Delay

- Perigee remains over the target zone for approximately 10 days
- Two back-to-back opportunities for Burns 2/3 on all but 1-2 days

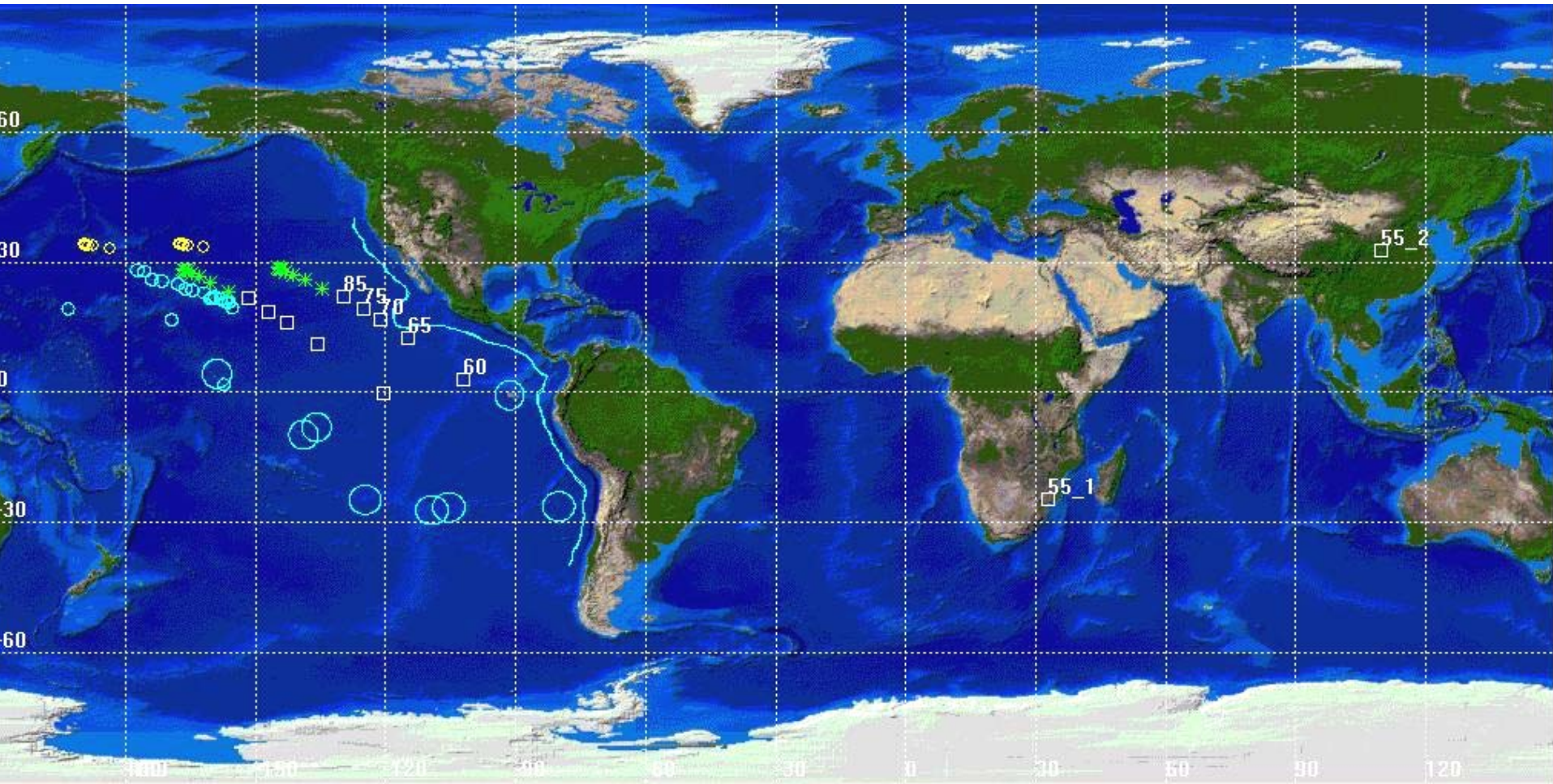


TRMM Impact Footprint
Effect of Burn 2 Delay



TRMM Impact Footprint – Short Burn 1

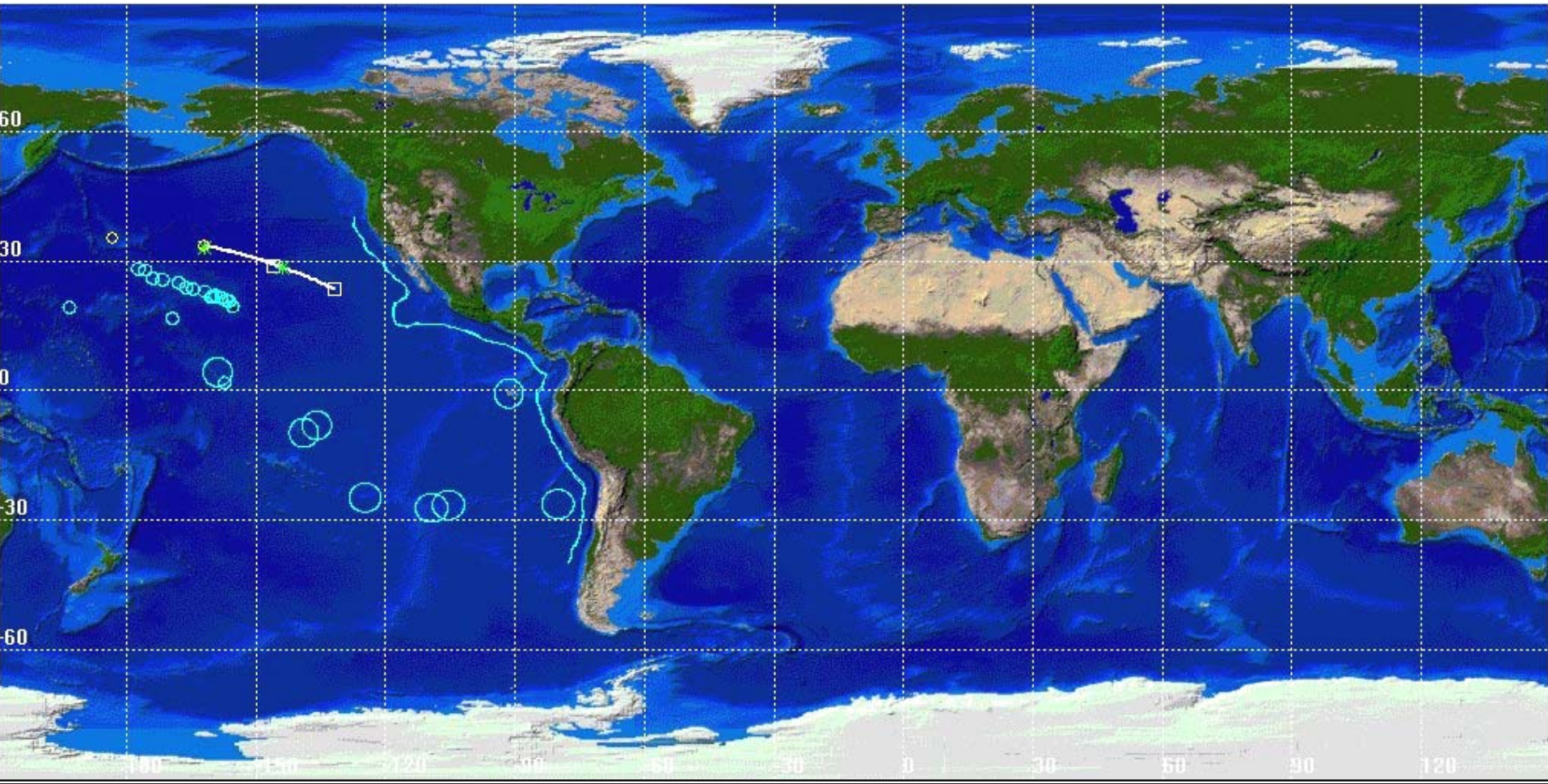
- Can tolerate burn length as low as 60% of nominal assuming subsequent burns are nominal
- May vary with ground track geometry



TRMM Impact Footprint

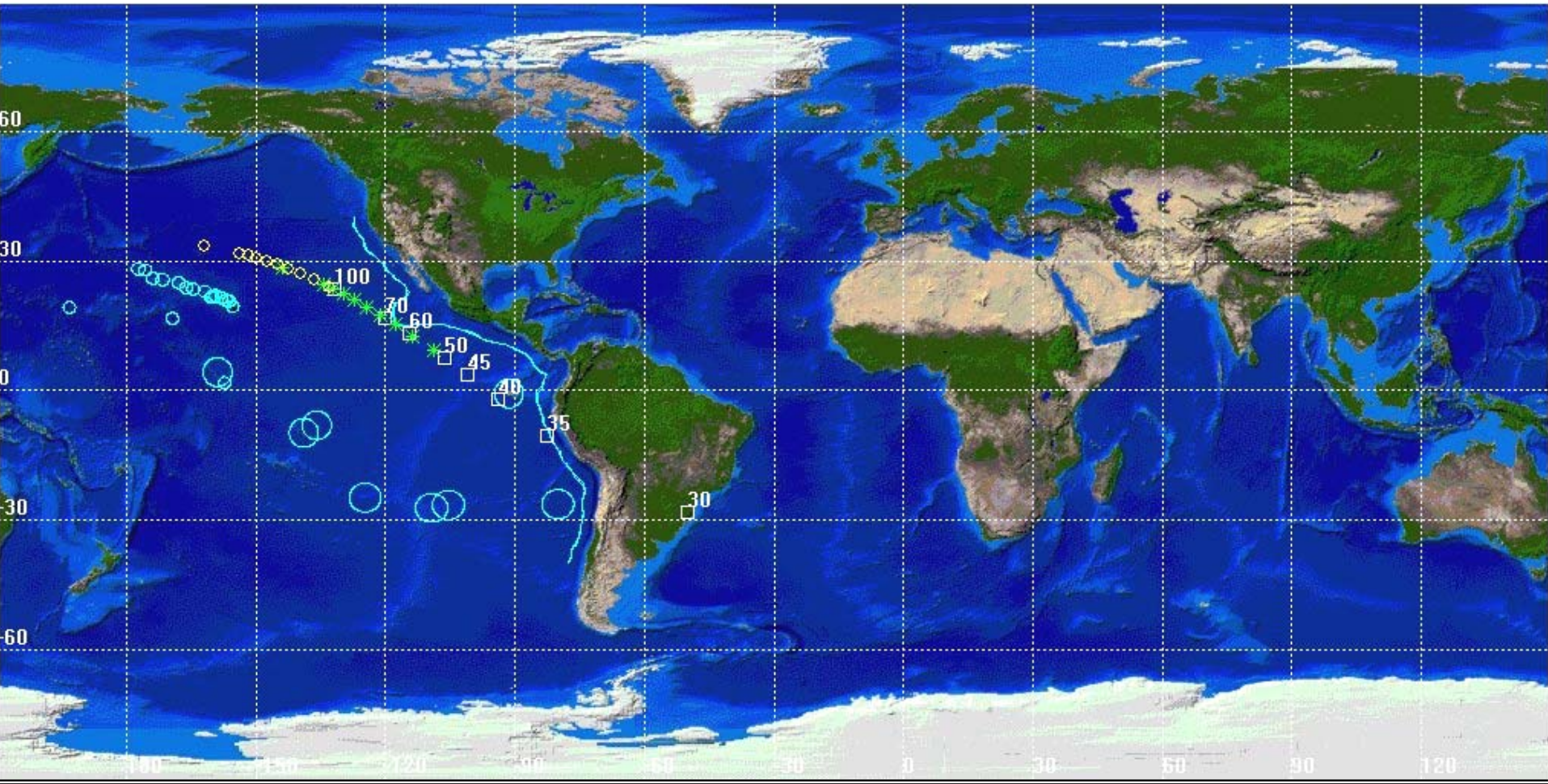
65% Burn 1 with Extended Burn 2

- Can tolerate burn length as low as 65% of nominal.
- Burn 2 lengthened to approximately 30 minutes to achieve initial targets for Burn 3



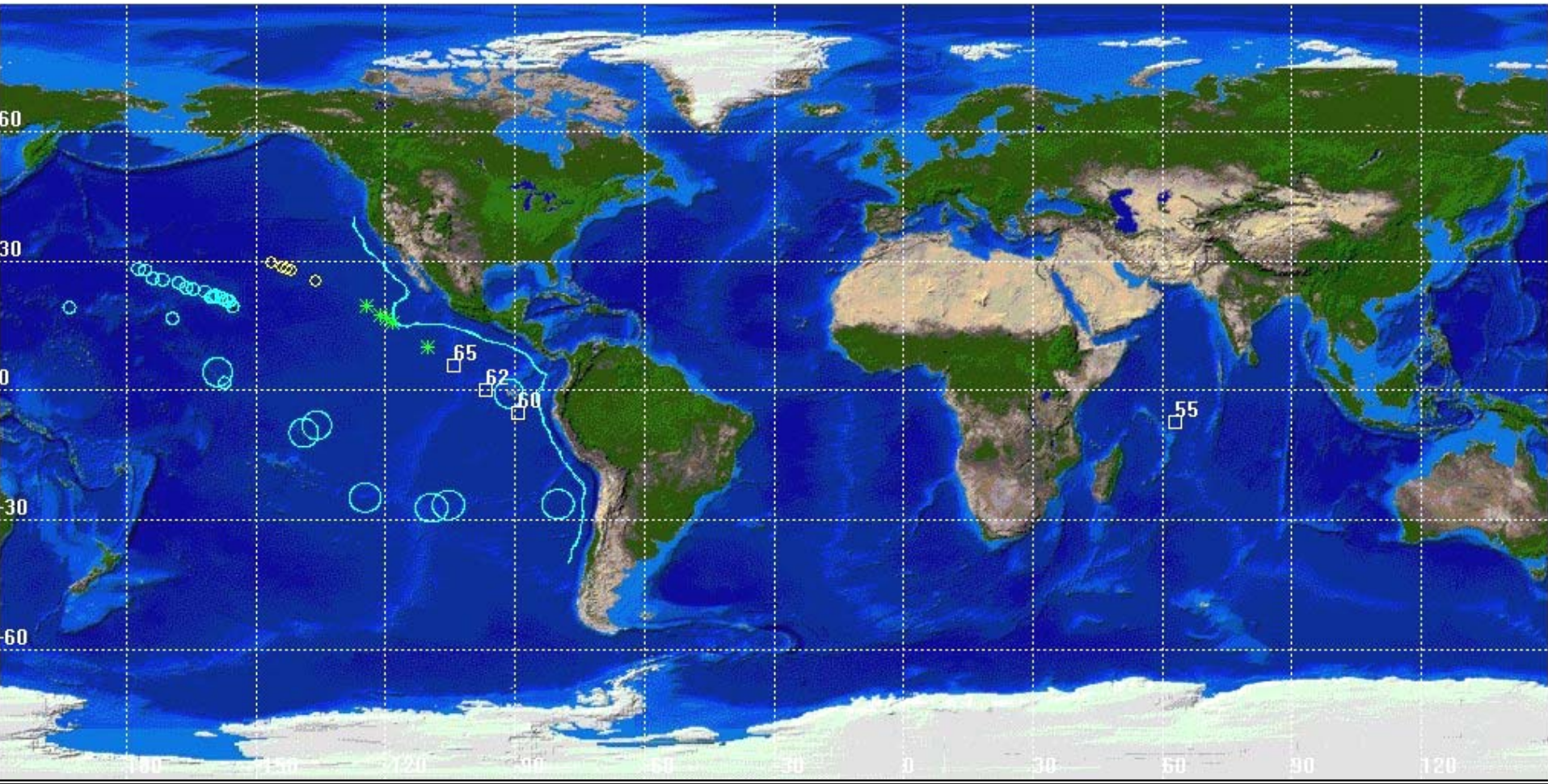
TRMM Impact Footprint – Short Burn 2

- Can tolerate burn length as low as 45% of nominal assuming subsequent burn is nominal.
- May vary with ground track geometry



TRMM Impact Footprint – Short Burn 3

- Can tolerate burn length as low as 62% of nominal.
- May vary with ground track geometry



TRMM Impact Footprint – Long Burn 3

- Burn 3 can be extended to approximately 43 minutes
- Burnout at approximately 140 km
- Requires approximately 9 kg of additional fuel